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GEOLOGIC SETTING AND DEFORMATIONAL HISTORY OF UMM NAR BIF AND ASSOCIATED ROCKS, EASTERN DESERT, EGYPT

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The Umm Nar area is covered by three tectonostratigraphic units: 1) metasediments and BIF, 2) ophiolitic mèlange, and 3) "Shaitian" sheared granite. These units are intruded by grey granites, younger gabbros, pink granites and basic and acidic dykes. The metasediments are subdivided into two stratigraphic zones: a lower zone of paraschists (mica and amphiloble schists) and marbles and an upper zone consisting mainly of BIF and mica schists which grade laterally into or intertongue with pebbly schists intercalated with quartzite bands. The ophiolitic mèlange unit consists of allochthonous oceanic and continental fragments embedded in a fine-grained and pervasively sheared matrix of graphite schists, talc carbonates and serpentinites with less abundant slate, phyllonite and chlorite schists. Dismembering, tectonic mixing and transportation are the essential processes in the formation and deformation of the mèlange rocks. The metasediments and mèlange rocks bear evidence of four phases of deformation including thrusting and folding, associated with mega-, meso- and micro-structures of different styles and attitudes and sequential stages of pre-, syn- and post-kinematic crystallization of minerals. The oldest phase is manifested by rootless intrafolial folds that are encountered within iron ore bands and a bedding plane parallel schistosity ($S_1//S_0$). During the Pan-African tectogenesis, the mèlange rocks were thrust over the metasediments and BIF, and both units were subsequently folded and deformed. These two units were thrown into NW-SE oriented major overturned anticlinal and synclinal folds which in turn were thrust (from the present SE to NW) onto the "Shaitian" sheared granite. The last phase of deformation, represented by NNE-SSW oriented open folding, affected the three tectonostratigraphic units.

The original sedimentary facies, composition and structures, degree of metamorphism, tectonic setting and style of deformation of the metasediments and BIF led to the conclusion that they belong to pre-Pan-African shelf deposits accumulated along an old continental margin and were regionally metamorphosed up to the low amphibolite facies, prior to the thrusting of ophiolitic mélange.

INTRODUCTION

The Egyptian Precambrian iron formation (BIF) and the host metavolcanics or metasediments constitute widespread and easily recognizable sequences at 134 localities distributed in the Central Eastern Desert (CED) between latitudes 25° 12' and 26° 31'N. These BIF sequences are considered, in the recent literatures, to be genetically related to Pan-African weakly metamorphosed island arc assemblages (Late Proterozoic) which are often associated with ophiolitic mélange rocks. However, the understanding of the environment of deposition and geologic setting of each BIF-bearing sequence is very important to unravel the origin of the related BIF facies as well as its genetic relationship with the complex history of the Pan-African rock assemblages. Therefore, one of the largest iron formation occurrences, namely Umm Nar (Fig. 1), is selected to clarify the geologic setting and mode of occurrence of the BIF facies and the associated rocks. The BIF sequence and the associated rock units of this area, their tectonic style, structural characteristics, metamorphic grade, lithologic associations and paragenesis, considering the modifications caused by metamorphism and deformations, are examined and discussed. Accordingly, a clear picture of the mode of formation and deformation history of the BIF and the host metasediments of this area and their tectonic relation with the associated rock units (i.e. mélange rocks and "Shaitian" sheared granite) can be deduced.

Geological, structural and petrographical studies of Umm Nar iron ore deposits are included in the publications of Akaad and El Ramly (1963a), El Ramly et al. (1993), Ramsy (1968), Abdel Wahed (1977), El Manawi (1991) and El Aref et al. (1963). Two main genetic models have been postulated for the Precambrian Egyptian BIFs including the Umm Nar occurrence: 1) a purely sedimentary origin during the accumulation of the Precambrian geosynclinal sediments (El Shazly, 1957, Shukri et al., 1959, Ramsy, 1968), and 2) a volcanogenic origin related to submarine magmatism and hydrothermal activity of Pan-African island arc assemblage (Bishara and Habib, 1973, Ivanov et al., 1973, Garson and Shalaby, 1976, Sims and James, 1984, El Gaby et al., 1988, Hussein and El Sharkawi, 1990). El Gaby et al. (1988) reported that the BIF and base metal sulphides of the Egyptian Eastern Desert (ED) occur exclusively in the Pan-African island arc assemblage and are of equivalent facies, where the iron oxides represent shallow shore environment to the north and the sulphides represent deeper euxinic environment to the south; Umm Nar BIF displays transitional

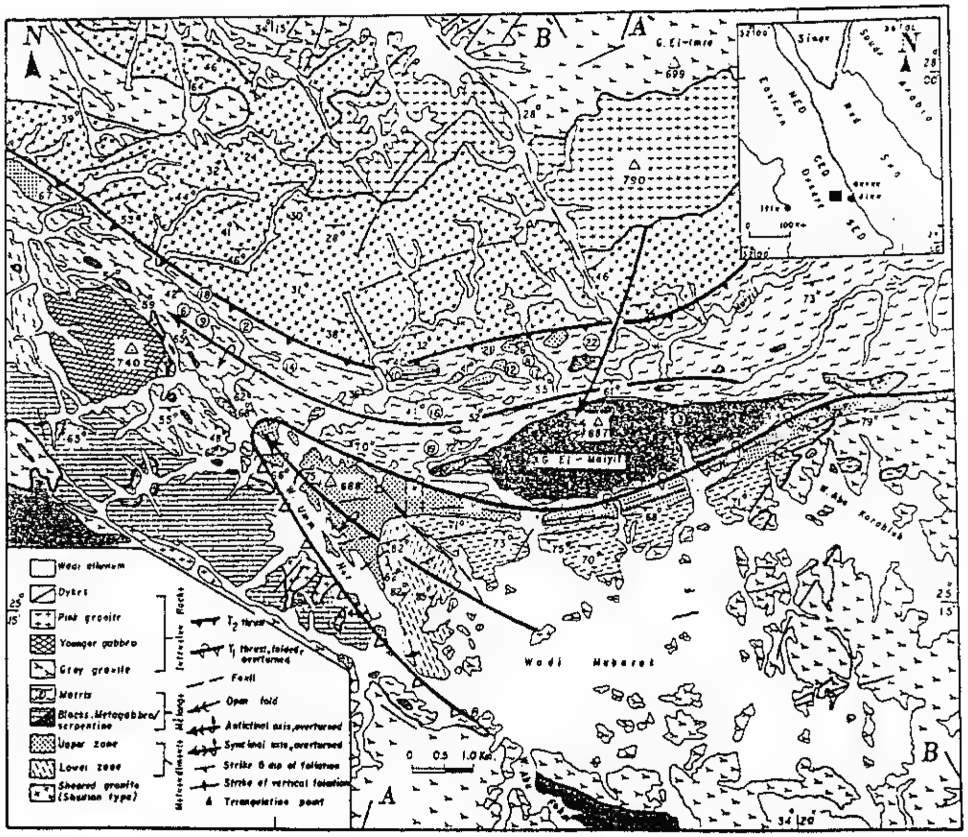


Fig. 1 Geological map of Umm Nar area, modified after Akaad and El Ramly (1963a). Encircled numbers mark locations of mélange fragments too small to represent on the map.

environment.

GEOLOGIC SETTING

The study are (Fig. 1) is a part of the Arabian Nubian shield which constitutes the northeastern sector of the Pan-African (650-550 Ma; Clifford, 1970) tectonic belt. It is bounded by latitudes 25° 12' to 25° 21'N and longitudes 34° 12' to 34° 21'E. The BIF of this area is closely associated with a widespread and thick succession of shelf deposits that were regionally metamorphosed up to the amphibolite facies, prior to the thrusting of ophiolitic mélange and the successive deformations of the Pan-African episode. In this area, the metasediments and BIF succession together with mélange rocks and sheared granite ("Shaitain" granite) constitute three tectonostratigraphic units separated by thrust faults (T_1 and T_2; Figs. 1, 2 and 3 a,b,c). The discrimination of the three tectonostratigraphic units is based upon their tectonic style, structural trend, metamorphic grade and lithologic association of each unit. They are intruded by grey granites, younger gabbros, pink granites and basic and acidic dykes.

The three recognized tectonostratigraphic units bear signs of different deformation phases, that were generated before the emplacement of syn- to late-orogenic Pan-African granitoids. The ophiolitic mélange was thrust over the underlying metasediments and enclosed BIF along an old thrust (T_1). These two units were thrown into steep overturned anticlinal and synclinal folds with axes trending NW-SE and plunging NW. The "Shaitian" sheared granite acted as a passive margin or swell during the thrusting and folding phases. A young thrust (T_2) carried the accreted and folded mélange rocks and metasediments with BIF over the "Shaitian" granite. The two folded units together with the underlying sheared granite were affected by a major open fold trending NNE-SSE. Dynamic metamorphism is prominent along the decollement surfaces leading to the formation of sheaths of talc carbonates and chlorite schists along the older T_1 thrust and fine-grained mylonites along the younger T_2 thrust.

LITHOLOGY OF THE THREE TECTONOSTRATIGRAPHIC UNITS

Metasediments and BIF

This unit comprises different types of schists intercalated with groups of iron ore bands forming together a major overturned anticlinal fold. The metasediments constitute a succession of ancient pelitic and calcareous sediments and sandstones now transformed into different varieties of mica schists, amphibole schists, marble and quartzite as a result of low to medium-grained regional metamorphism. Bedding is the main primary structure inherited from the parent sediments, reflecting the difference in the original composition of the alternating bands. For the detailed studies of the lithological variations of this unit, samples were collected along four principal traverses nearly perpendicular to the strike of the sedimentary succession (Fig. 4). The four profiles were selected to include the whole range of stratigraphic and lithologic variations of this unit. The whole succession can be subdivided into two conspicuous lithologic zones. The lower zone, 140 to 260 m thick, occupies the core of the major overturned anticline and includes successions of strata consisting of mica and amphibole schists with less predominant marble intercalations. The mica schists form low to moderate relief outcrops depending on the degree of weathering. They are fine to medium-grained, and have a variegated colour and a silvery luster. They may contain augens of quartz reaching up to 5 mm in diameter. The amphibole schists form higher relief and are generally hard, medium-grained and contain dark brown garnet porphyroblasts. Marble is of limited distribution and is only recorded in the western side of the northern limb of the major anticline. The marble bands are rhythmically alternated with bands of amphibole and mica schists forming a zone of about 20 m thick. They have sharp contacts against the surrounding rocks and exhibit minor folding. The upper zone, 75 to 300m thick occupies the crest and the flanks of the anticline and extends along the northern limb for a distance of about 7.5 km. It consists mainly of stratiform BIF layers intercalated with mica schists and less abundant amphibole schists. The iron ore occurs as separate bands or in groups varying in thickness from a few centimeters to a maximum thickness of about 5m at the crest of the anticlinal fold, where they can be traced for a long distance. The iron ore bands within a single group are separated by thin intercalations of biotite schists, while amphibole schists are recorded between the iron ore groups.

The BIF bands show rythmic lamination (varve-like), cross lamination and a flaser structure. The thickness of the iron bands decreases gradually from the crest towards the anticlinal limbs, along which the iron ore forms small and separate lenticular bodies. At section D, the BIF is completely missing and the upper zone of this section is made up mainly of repeated alternations of biotite schist, pebbly biotite schist and quartzite bands, with individual bands up to 20 cm thick each. Westwards, these intercalations grade laterally into and intertongue with the BIF bands and the associated schists. The enclosed pebbles are of variable sizes and made up of granite, marble and quartzite. They are highly stretched and flattened showing elliptical cross-sections and are usually aligned parallel to the bedding of the host rocks.

The mica and amphibole schists and the associated BIF are intensively cataclased along the thrust contact with the mélange complex. The northern inverted limb of the overturned anticline and the thrust contact are intruded by massive grey granites, best seen along W. Abu-Karahish and W. Mubarak. The intrusive granite contains a large number of rafts and enclaves of schists which are mainly oriented in a E-W direction. The internal schistosity of these rafts is generally parallel to the general foliation trend of the intruded metasediments.

Ophiolitic mélange

In the previous geologic maps of Akaad and El Ramly (1963 a), El

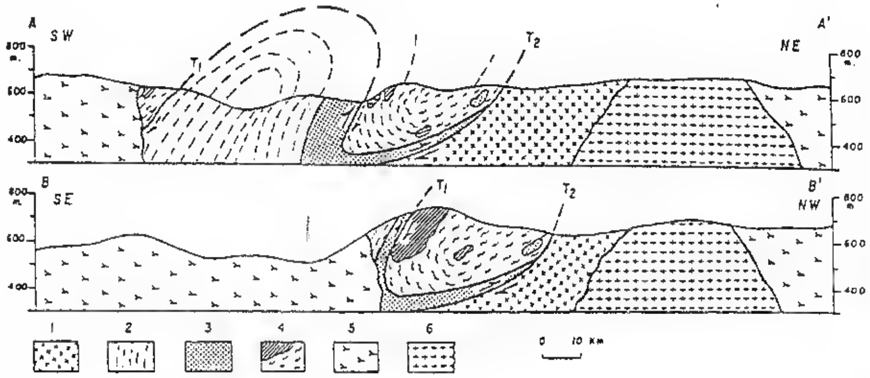
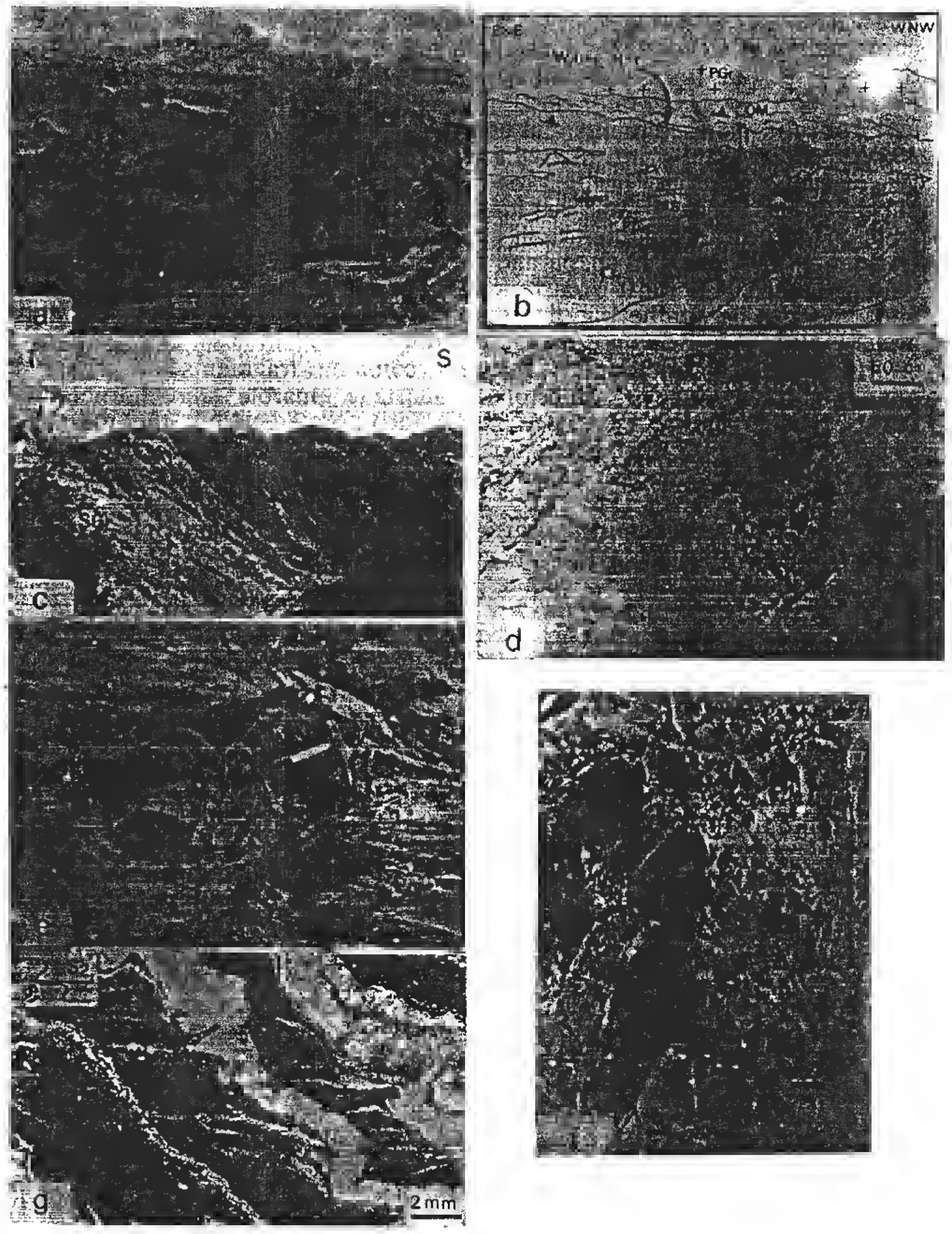


Fig. 2 Cross-sectional profiles A-A' and B-B' (location in figure 1). T_1 = Thrust contact between the metasediments with BIF and the mélange unit; T_2 = Thrust contact between the folded metasediments and mélange rocks and the sheared granite; 1= "Shaitian" sheared granite, 2= Metasediments (lower zone); 3= Metasediments (upper zone, BIF bearing zone); 4= Mlange rocks; 5= Grey granite; 6= Pink granite.

Fig. 3 3 a.b: Field photograph and explanatory sketch showing the T_1 thrust between ophiolitic mélange (OM) and metasediments and BIF (MS). PGr = Pink granite of Gabal Abu Diah. 3c: Field view showing the T_2 thrust contact between ophiolitic mélange (OM) and sheared granite (SGr). 3d: Isolated block of metagabbro surrounded by talc carbonate, Wadi Umm Nar. Photo looking SW. 3e: Fractured granite fragment surrounded by highly sheared matrix, north Gabal El Maiyit. Photo looking N. 3f: Very tight F_1 fold of BIF included within the bedding foliation of mica schist. Photo looking NW. 3g: F_2 microfolds superposed on S_1 schistosity and associated with S_2 secondary foliation.

Fig.3



Ramly (1972) and Dardir et al. (1989) the ophiolitic mélange was not identified as such and was described and mapped either as "schist-mudstone-greywacke" series or geosynclinal metasediments and metavolcanics, conformably overlying the metasediments and BIF sequence. The bulk of this mélange unit forms a major overturned synclinal fold striking in a NW-SE direction (Fig. 1). Major thrust faults (T_1 and T_2, Figs. 1, 2) separate this unit from the metasediments and associated BIF and the "Shaitian" sheared granite. Grey granite intruded these folded and thrusted mélange rocks. The mélange unit is of heterogeneous character being composed of allochthonous oceanic and continental fragments (chaotic fragments) embedded in an incompetent and pervasively sheared matrix (Fig. 1). The fragments vary greatly in shape and size and are randomly distributed in the mélange matrix. In most occurrences, they are found on hillsides or hilltops and appear to be weathering out of the matrix. The most common fragments are ophiolitic in composition including serpentinites, metagabbros, anorthosite and hornblendite; the less common fragments are sheared granite, metagreywackes, mudstones, quartzite, marble and hornblende schists. Slivers of the BIF, tectonically incorporated within the mélange rocks, are commonly distributed along the T_2 thrust (Locs. 10, 11, 12, 13; Fig. 1). This indicates tectonic mixing of the BIF slivers with the mélange components during the T_2 thrust phase. Most of the mélange fragments are highly sheared along their margins and show obvious transition into the sheared matrix. Primary synsedimentary structures such as rhythmic, even or convolute, lamination and bedding, cross lamination, graded bedding and slumping are observed only in few sedimentary fragments. The primary bedding of such fragments is often oriented parallel to the mylonitic schistosity of the mélange matrix or reoriented along local faults.

Serpentinite fragments range from sand and pebble size to huge mountain size of high relief; e.g. Gabal El Maiyit (887 m a.s.l.). Large fragments often form isolated lenticular masses or a more or less continuous belt of distrupted boudins arranged parallel to the matrix foliation. The serpentinite fragments mostly attain a schistose habit along their outer margins and are sometimes traversed by veinlets of carbonates and asbestos. Ophiolitic metagabbro fragments (locs. 1, 2 Fig. 1) are mainly found in tectonic contact with the large serpentinite masses or occur as individual blocks or in groups surrounded by a sheared matrix (Fig. 3d). A large mass of disrupted and highly sheared metagabbro, associated with a talc carbonate matrix, crops out in the southwestern corner of the area. Fragments of cataclastic granite in the form of rounded blocks or elongated slabs are often arranged parallel to the surrounding sheared matrix (Locs. 5, 6, 7; Fig. 3e). They show a variable degree of cataclasis, from slight shearing up to strong mylonitization. Isolated blocks and cobbles of metagreywackes, mudstone and marble are irregularly distributed within the mélange matrix (Locs. 8, 9, 15; Fig. 1). Quartzite forms boudinaged blocks and disrupted beds conformable with the matrix foliation (Loc. 14; Fig. 1). Hornblende schists occurs as irregular masses or folded lenticular fragments (Locs. 16, 17, 18; Fig. 1).

The BIF slivers show a characteristic porphyroclastic texture, consisting of magnetite and quartz porphyroclasts in a fine-grained mylonitic groundmass. The quartz porphyroclasts are highly stretched, strongly undulose in extinction and wrapped around by the mylonitic schistosity of the groundmass. Later recrystallization is displayed by plagioclase, calcite and quartz porphyroblasts.

The mélange matrix displays a well developed mylonitic foliation running parallel to the two main thrust planes. It consists predominantly of graphite schists, talc carbonates and antigorite carbonate schists with less abundant slate, phyllonite and chlorite schist. These varieties are intimately intermixed at a millimetre scale. The matrix appears to be locally enriched in serpentine or graphite.

Sheared granite ("Shaitian" granite)

The rocks of this units form a curved elongated belt, about 16 Km long and about 4 km in its widest part. They are obviously intruded by grey and pink granitoids (Fig. 1). The "Shaitian" granites are fine to coarse-grained, dull greyish in colour, and show a distinct shear structure conformable with the mylonitic foliation of the ophiolitic mélange rocks. The degree of cataclasis ranges from mildly cataclased rocks to proper mylonites near and along the T_2 thrust boundary against the ophiolitic mlange unit. Quartz porphyroclasts usually stand out on the weathered surfaces of the sheared rocks and appear as elliptical pebble-like bodies, thin flat eyes or lenticles. The mylonites are extremely fine-grained, leucocratic, vary in colour from pale greyish brown to pale buff and pale cream with a faint greenish tint. The mafic constituents do not occur as well defined crystals or grains but usually form blurred patches of a greenish colour.

STRUCTURAL AND DEFORMATIONAL HISTORY OF THE TECTONOSTRATIGRAPHIC UNITS

To elucidate the relationship between these units, the structural elements characteristic to each unit are separately studied in detail. Table (1) summarizes the results of the present observations and illustrates the main deformation phases and related structural features recorded in each unit. The different phases of deformation are recognized on the basis of their different styles of folds and schistosities as well as by their overprinting relationships. An old deformation phase (DMo) is believed to be responsible for the dismembering and tectonic mixing that tookplace in conjunction with thrusting (but outside the study area) prior to the observed thrusting of the ophiolitic mlange over the metasediments and BIF unit.

Metasediments and BIF

Very tight closures or rootless intrafolial folds, representing the oldest F_1 folding phase, are frequently observed within the schist and BIF bands (Fig. 3f). As mentioned before, the metasediments and BIF are separated from the mélange rocks by an old thrust (T_1) and are thrown into a steep

Table 1 Deformational phases and the associated structural features observed in the three tectonostratigraphic units.

Oeformational Phases			Metasediments and associated BIF unit	Ophiolitic melange unit	"Shaitian" Sheared granite
D_1	F_1	:	Rootless intrafolial folds	OMo(?)	
	S_1	:	Bedding parallel schistosity (//So)		
	L_1	:	Linear boudinage crenulation lineation		
DM_1	T_1	:	Old thrust carried the melange rocks over the underlying metasediments and associated BIF with formation of mylonitic zone (SM_1)		
	SM_1	:	Mylonitic shistosity parallel to S_1		
D_2	F_2	:	Macroscopic anticlinal and synclinal folds associated with open to closed mesoscopic folds; progressively converted to macroscopic overturned fold with tightening of the mesoscopic folds; axes trending NW, folding of T_1 thrust.		
	S_2	:	Axial plane schistosity and strain-slip cleavage.		
	L_2	:	Mineral lineations, crenulation lineation, pencil structure, kink axes, boudinage of quartz veins, stretched quartz pebbles and oriented inclusions.		
	T_2	:	Younger thrust carried the folded melange rocks and the metasediments over the sheared granite, with creation of younger mylonitic zone (SM_2).		
	SM_2	:	Mylonitic scxhistosity. Creation of mineral lineation and slickenside striations on the surface of the younger mylonitic foliation, having NW trend.		
D_3	F_3	:	Major open folding together with open mesoscopic folds; axes trending NNE; refolding of F_2 folds, folding of T_2 thrust.		
	S_3	:	Axial plane schistosity and fracture cleavge.		
	L_3	:	Kink axes.		

overturned anticlinal fold (F_2 folding phase) associated with open to closed mesoscopic folds and folding of T_1 thrust. The axis of this fold trends NW-SE and plunges NW. F_2 folds warp S_1 bedding parallel schistosity and are related to an axial plane schistosity and strain-slip cleavage (Fig. 3g). The major fold was overturned to the north, accompanied with refolding and tightening of the associated mesofolds. The inverted northern limb extends for about 7.5 km, strikes E-W parallel to the serpentinite mass of G. El Maiyit and dips toward the S at an angle of about 75°. The southwestern limb extends for about 2.5 km, strikes NNW-SSE and dips toward the SW at an angle of about 65°. The northern limb was folded into a major open fold (F_3 folding phase) having an axis striking NNE-SSW (Fig. 5a). This F_3 folding phase led to the warping of the overturned northern limb and the related older foliations and the development of axial plane foliation, fracture cleavage, and conjugate kinks associated with conjugate shear fractures and pygmatic folds in older quartz veins. Younger generations of quartz veins along the resulting conjugate shear fractures are not uncommon. The major structures are frequently accompanied by different varieties of minor structures including complex patterns of minor folds, faults, joints, foliations and lineations. Most of the minor faults are not mappable, differing in scale from minor faults in handspecimen to mesofaults in a single exposure. Dragging frequently occurs along the fault planes. At the crest of the major anticline, the faults have NW-SE direction, while at the northern limb, they have NNE-SSW direction. At the southwestern limb, the faults have ENE-WSW direction. The mesofolds show wide variation in style, amplitude and orientation and are often accompanied by strain-slip cleavage. They include open concentric, closed or tight, symmetric and chevron folds. They vary in wave length from few millimeters to tens of meters and have variable attitudes of axial planes and fold axes depending on their position within the major fold and the folding phase (F_2 and F_3) they represent. Refolding phenomena is recorded among the isoclinal recumbent folds.

More than one trend of foliation are recorded, especially at the fold hinges. The main foliation (S_1) is the bedding plane parallel schistosity ($S_1//S_0$) which is parallel to lithologic layering and is regarded as the oldest foliation. It is formed most likely during burial metamorphism of the original sedimentary pile. At the northern limb of the major anticlinal fold, S_1 foliation strikes nearly E-W and dips about 75° S. At the southwestern limb, it strikes NNW-SSE and dips about 65° SW. At the crest of the major overturned anticline, S_1 foliation strikes differently from one place to another due to the influence of later deformations. The schists and BIF are highly sheared along the thrust contact with the mélange rocks. Shearing led to the development of mylonitic foliation (SM_1) parallel to the main S_1 foliation. NW-SE and NNE-SSW axial plane foliations (S_2 and S_3, respectively) cut across S_1 and SM_1 foliations and are parallel to the axial planes of F_2 and F_3 folds.

Various types of lineations, related to the different deformational phases, are recorded. Well developed boudinage structures (L_1) are essentially recognized in the quartzite and amphibolite bands. Quartzite and

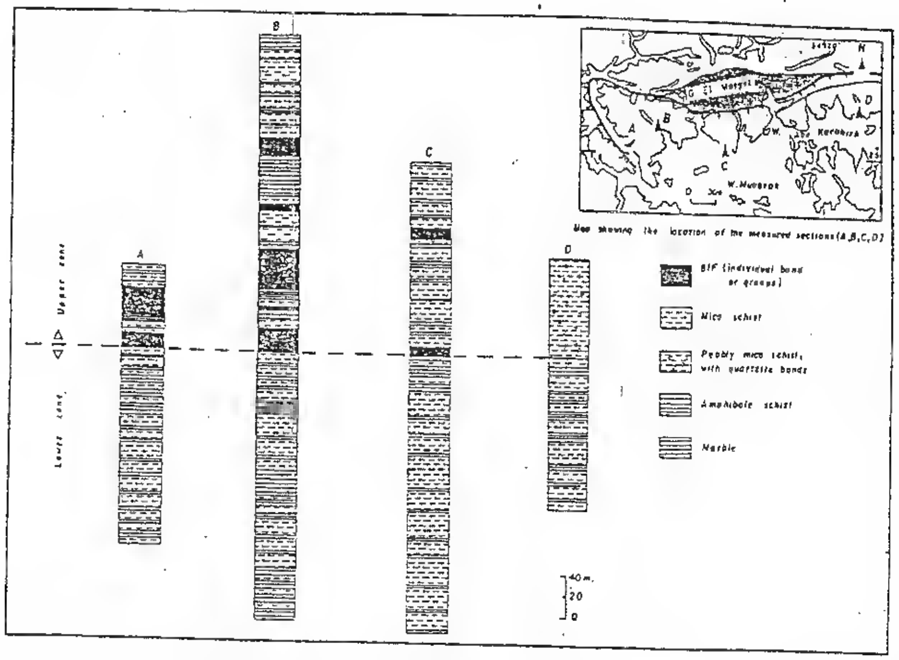


Fig. 4 Generalized lithostratigraphic sections of the metasediments showing the distribution of the associated BIF.

Fig. 5 5a: Open flexural slip fold (F_3) with axial trace trending NE. Photo looking S. 5b: L_2 crenulation lineation plunging SW along the bedding planes of BIF band at the southwestern limb of the major overturned anticlinal fold. Photo looking NE. 5c: L_2 pencil structure in hornblende schist at the southwestern limb of the major overturned anticlinal fold. Photo looking NE. 5d: Strong preferred orientation of biotite and chlorite along S_1 and s_2 folitations, biotite quartz schist, P.P.L. 5e: Stratiform rhythmic alternation of iron rich (1), garnet-rich (2) and quartz-rich (3) layers, P.P.L. 5f: Large garnet porphyroblast (G) contains helicitically linear inclusions (Si) concordant to the external foliation (Se), P.P.L. 5g: Post-S_1 muscovite (ms) helicitically encloses oriented inclusion of S_1 biotite (bt_1), C.P.

P.P.L. = Plane Polarized Light C.L. = Crossed Polarizers

Fig.5

amphibolite boudins elongated roughly parallel to the strike of the main S_1 foliation are common. L_2 and L_3 kinking axes associated with conjugate shear fractures are present in some bands of mica schists and BIF. The L_2 mineral lineation is well developed and frequently observed along the foliation planes of different types of schists and BIF. L_2 oriented hornblende with or without biotite, is generally present in amphibole schists, L_2 mica, on the other hand, is found mostly in mica schists, L_2 hematite, slipnomelane and muscovite are well represented in BI intervals. L_1 and L_2 crenulation lineations are essentially observed along the bedding planes of the iron ore bands parallel to the axes of F_1 and F_2 minor folds (Fig. 5b). Some quartz veins which cut the S_1 foliation have been stretched and are broken in regular intervals, forming a linear aligned boudinage structure (L_2 boundinage lineation), arranged parallel to subparallel with L_2 mineral lineations. Pencil structure resulting from the intersection of S_1 and S_2 foliations is well developed along the southwestern limb of the major anticline (Fig. 5c).

Microscopically, the mica schists comprise varieties of crystalloblastic muscovite, biotite and chlorite and include quartz and plagioclase of variable proportions. The amphibole schists comprise varieties of crystalloblastic hornblende, chlorite and actinolite and contain biotite, calcite, almandine garnet, epidote, plagioclase and quartz. Pre-S_1 primary precipitates such as hematite dust, cryptocrystalline quartz, ultrafine-grained magnetite and micritic calcite show depositional salt and pepper texture and often form rhythmic stratiform bands and laminae conformable with the S_1 foliation. Marbles consist mainly of calcite, tremolite and chlorite. Sillimanite and cordierite were recorded in subsurface samples (Ramsy, 1968). The textural relations between the mineral constituents of these rock varieties led to the recognition of seven stages of crystallization that prevailed during the metamorphic and deformational history of these rocks. Stage I is pre-S_1 and is characterized by randomly distributed quartz, hematite dust and biotite, that are included in other minerals gown during subsequent stages of crystallization. Stage II is demonstrated by the development of the main S_1 foliation depicted by the preferred orientation of elongate crystals of chlorite, muscovite, biotite, hornblende, actinolite and hematite (with quartz, plagioclase, garnet and calcite), (Figs, 5 d,e). Stage III comprises post-S_1 and SM_1 interkinematic stage, recognized by porphyroblastic growths of quartz, chlorite muscovite, almandine garnet, plagioclase, epidote, hornblende, calcite and magnetite (Figs. 5 f,g). Stage IV is characterized by the S_2 axial plane foliation, overprinting the S_1 foliation. A younger generation of chlorite, quartz, muscovite, biotite, hornblende and actinolite developed along S_2 foliation. Stage V is represented by post-S_2 interkinematic mineral growth, manifested by large porphyroblasts of quartz and plagioclase helicitically enclosing pre-existing minerals. Stage VI is represented by the less distinct S_3 foliation delineated by reoriented S_3 biotite or actinolite, intersecting older foliations, and/or by fracture cleavage filled with actinolite (Fig. 6a). Stage VII represents a retrogressive episode, manifested by the alteration of biotite and hornblende to chlorite, garnet to biotite or chlorite and plagioclase to kaolinite.

Mèlange unit

The main structural elements observed in the mèlange unit are parallel to their equivalents in the metasediments and associated BIF and belong to F_2 and F_3 folding phases and T_1 and T_2 thrusts. The bulk of this ophiolitic mèlange forms a major overturned synclinal fold (F_2), with an axis striking in a NW-SE direction. Two main shear zones (SM_1, SM_2) are well developed along the T_1 and T_2 thrust planes. The younger SM_2 shear zone always dips 40° toward the south, whereas the older one dips 65° toward the south. Minor folds, mylonitic foliations and lineations are the essential tectonic features observed in the mèlange unit. Mesoscopic tight symmetric and asymmetric as well as open folds related to the NW-SE or NNE-SSW folds (F_2 and F_3) are frequently observed (Fig. 6b). Superposed structures are also common (Fig. 6c). The orientation of the mylonitic foliation is generally concordant with the S_1 foliation of the metasediments and BIF as a result of the coincidence of these foliations with that of the thrust planes. In some places, SM_1 foliation shows variable attitudes due to the effect of the subsequence folding. In the central part of the mèlange unit, SM_1 foliation strikes nearly E-W and dips about 65° S near the older thrust (T_1) and about 40° S near the younger thrust (T_2). At the western part, it strikes NW-SE and dips about 55° SE. At the eastern part, it strikes NE-SW and dips about 50½SE. Axial plane foliations (S_2 and S_3) cut across the SM_1 and/or SM_2 foliations. Various types of lineations are recognized. L_2 kinking axis trending NW is the most abundant type of lineation exhibited in the matrix. Kinks form conjugate folds (Fig. 6d). Slickenside lineations which indicate the movement of the younger thrust plane (T_2) are dominantly well developed in the distributed BIF fragments (Fig. 6e). They trend NW and plunge at about 35° SE, which are conformable with the slickenside lineations of the underlying sheared granite. Some quartz pebbles encountered within the matrix have been stretched, forming elongated inclusions arranged parallel or subparallel to the main foliation planes.

Considering the deformational history of the sheared mèlange rocks, five stages of crystallization equivalent to stages III to VII of the metasediments and BIF, are recorded. These stages started with the oldest SM_1 mylonitic foliation and include the following: Stage 1 (syn-DM_1), manifested by the dominant SM_1 mylonitic foliation which was accompanied by the crystallization and/or recrystallization of quartz, chlorite, hornblende, plagioclase, calcite, graphite, antigorite, talc and less abundant epidote, magnetite, biotite, muscovite and actinolite. Stage 2 comprises the mineral growths during the post-DM_1 interkinematic stage, displayed through the development of porphyroblasts of quartz, chlorite, hornblende, tremolite, plagioclase, calcite, garnet and magnetite. Stage 3 encompasses the crystallization of hornblende and tremolite developed along the S_2 axial plane foliation. Stage 4 comprises the post-D_2 interkinematic growth of large hornblende porphyroblasts enclosing pre-existing minerals (Fig. 6f). Stage 5 is manifested by the alteration of serpentine to talc carbonate and plagioclase to kaolinite, that took place during the retrogressive episode.

Fig.6

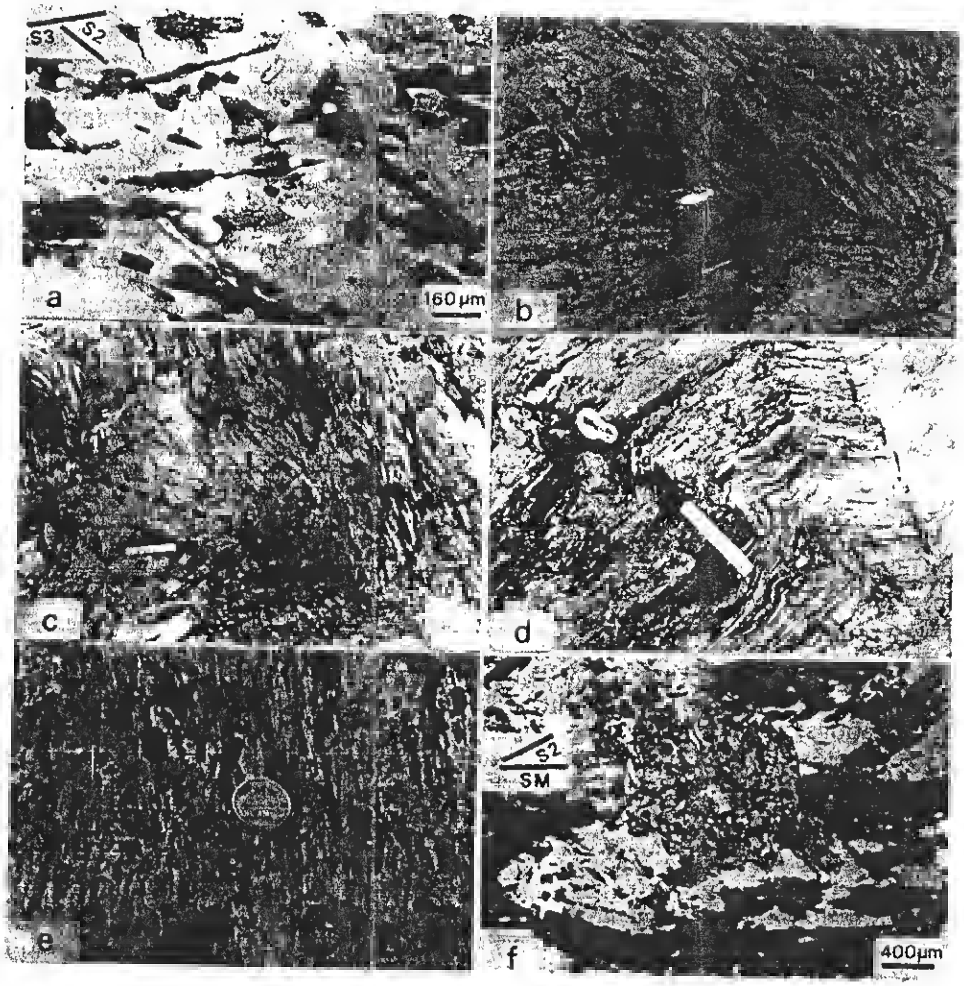


Fig. 6 6a: S_2 and S_3 biotite foliations in hornblende biotite schist, P.P.L. 6b: Tight overturned F_2 fold in talc carbonate and graphite schists with axis trending N 60° W, western part of the ophiolitic mélange unit. 6c: Tight F_2 fold with axis trending N 70° W, superposed by open F_3 fold, Wadi Umm Nar. Photo looking W. 6d: Conjugate F_2 folds, in talc carbonate and graphite schists with axes trending N 70° W, western side of Talet Umm Efin. Photo looking W. 6e: NW trending slickenside lineation (L_2) on the surface of mylonitic foliation of BIF fragment. 6f: Post-S_2 hornblende grows across SM_1 and S_2 schistosities, hornblende schist fragment in ophiolitic mélange, P.P.L.

Sheared granite ("Shaitian" granite)

The sheared granite shows only evidence of SM_2 mylonitic foliation associated with the T_2 thrusting event as well as open folding of F_3 folding phase. The induced foliation of the sheared granite are most commonly associated with mineral lineation and slickenside striation, trending in a NW direction and plunging at about 35° SE. Mimetic crystallization of younger quartz is recorded on the foliation planes parallel to slickensides and mineral lineations. The elongated belt of this sheared granite is affected only by macroscopic and mesoscopic F_3 open folds, with axes trending in a NNE-SSW direction.

DISCUSSION AND CONCLUSIONS

1. Umm Nar area, ED, Egypt is largely occupied by rocks pertaining to three tectonostratigraphic units viz Figure 7 sheared granite, metasediments and BIF and ophiolitic mélange. These units were intruded by undeformed Pan-African grey granites, younger gabbros, pink granites and basic and acidic dykes. The structural history of these three tectonostratigraphic units is schematically illustrated in Fig. 7.

2. The sheared granite in the study area was correlated with the "Shaitian granite" of Wadi Shait and was considered equivalent to the grey granites or synorogenic plutonites of the ED (El Ramly and Akaad, 1960; Akaad and El Ramly, 1963 a, b; El Shazly, 1964; E; Shazly et al., 1971; El Gaby and El Aref, 1977). The "Shaitian" granites gave whole-rock Rb-Sr age of 876 Ma in their type locality at Wadi Shait (Hashad et al., 1972) and 883 Ma in the study area (El Manharawy, 1977). El Gaby et al. (1988) and List et al. (1989) suggested recently that the "Shaitian granite" is a part of the "infrastructure", representing the margin of the old continental mass, over which Pan-African ophiolites and island-arc volcanics and volcaniclastics have been thrust as a "suprastructure". The present observations support this conclusion, depending upon the following criteria: a. The mélange rocks and metasediments were thrust over this type of granite accompanieby the development of a mylonitic zone of large extent along the thrust plane. b. The conformity between the myionic foliation in the sheared granite and the SM_2 mylonitic foliation in the overthrusted mélange rocks and metasediments. c. The development of mineral lineation and slickenside striation in the sheared granite marking the direction of movement during the T_2 thrust event. d. The folding of the three tectonostratigraphic units by the NNE open fold (F_3). e. The three tectonostratigraphic units are intruded by grey granites that do not show any evidence of post emplacement deformation related to any of the deformational episodes recorded in the mélange rocks, metasediments or "Shaitian" granite. f. The occurrence of granitic pebbles and cobbles, similar in composition to the mylonitic granite, within the metasediments as well as blocks of sheared granite within the mlange unit. The absence of deformational features older than the T_2 thrusting phase in the "Shaitian" granite is attributed to the assumption that the deformational features related to T_1 and T_2 observed in the meta-

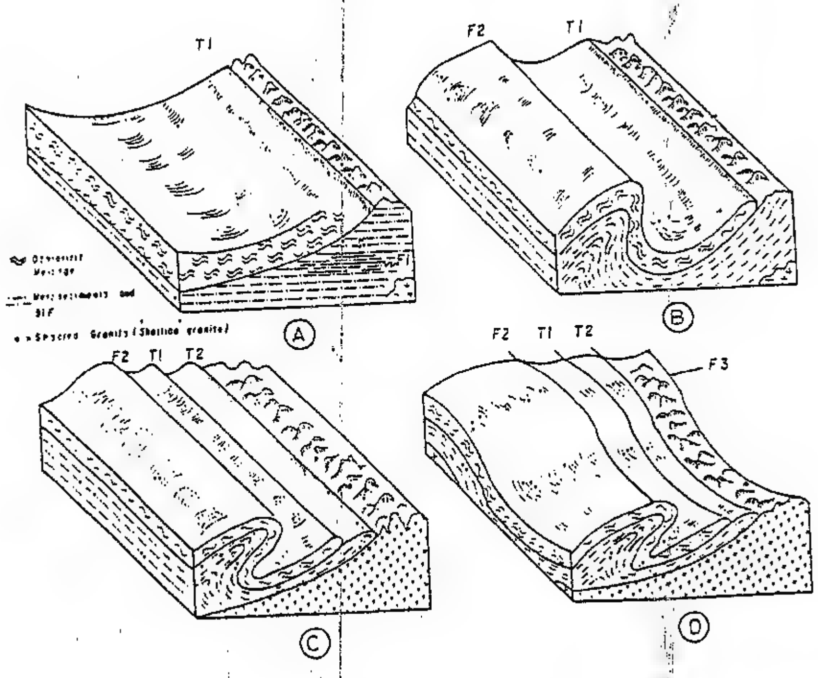


Fig. 7 Schematic diagram summarizing the structural history of the recognized three tectonostratigraphic units: F_1 = rootless interfolial folds within metasediments and BIF unit.
A: T_1 thrusting of ophilitic unit over metasediments and BIF.

B,C: F_2 folding with folding of T_1 thrust; T_2 thrusting of the ophiolitic mèlange and metasediments with BIF units over the "Shaitian" sheared granite.
D: F_3 open folding.

sediments and ophiolitic mèlange took place somewhere else prior to their transportation and thrusting over the "Shaitian" granite.

3. The geosynclinal metasediments and Shadli metavolcanics, serpentinites and metagabbro-diorite complex of Akaad and El Ramly (1960, 1963 a) and El Ramly (1972) and the Abu Ziran and Rubshi groups of Akaad and Noweir (1980) are interpreted and described as Pan-African ophiolitic mlange (Shackleton et al., 1980) that commonly located as imbricated thrust sheets ("suprastructure") thrust over the Early Proterozoic continental crust or "infrastructure" (El Gaby, 1983; El Gaby et al., 1984; List et al., 1989). Several authors defined these ophiolitic rocks as remnants of oceanic crust obducted along distructive plate boundaries after the closure of small ocean basins (e.g. Frisch and Al Shanti, 1977; Gass, 1977, 1979; Stern, 1979; Kemp et al., 1980, 1982; Shackleton, 1980; Shackleton et al., 1980; Kröner et al., 1987; Vail, 1988). Others believed that these ophiolites have developed in back-arc basins (e.g. Stern, 1981; El Bayoumi and Greiling, 1984; El Gaby et al., 1984; Kröner, 1985). Church (1986, 1988) argued that the ophiolites of the Arabian-Nubian Shield constitute a single stratigraphic horizon and that their present distribution is controlled by first order structures and consequently they do not necessarily demarcate the original sites of ocean basins or suture boundaries. Shackleton et al. (1980), Ries et al. (1983), and Shackleton (1986) suggested that these mèlange rocks were developed initially as olistostromes by gravity sliding and subsequently thrust over continental shelf sediments during subduction from the present southeast direction. El Gaby (1983), El Ramly et al. (1984) and Kröner (1985) believed that the Pan-African belt was created by E-W compression while Shackleton et al. (1980) and Greiling (1987) assume a general NW-directed transport for the major part of the ED of Egypt.

The composition and structural characteristics of the mèlange components of the study area and their relation with the surrounding rocks (metasediments and "Shaitian" granite) emphasize that dismembering, tectonic mixing and transportation are the essential processes in the formation and deformation of these mèlange components. Tectonic transport is evident by the different varieties of major and minor structures (thrusting, shearing, folding slickensides, and mineral lineation etc.). Slickenside and mineral lineation along the youngest thrust plane (T_2) indicate that the last tectonic movement in the study area was to the NW.

4. The original sediments of the BIF host rocks were most probably sandy and calcareous shales or mudstones, sandstones, limestone and magnesian limestones now metamorphosed under greenschist and low amphibolite conditions into garnet-bearing mica and amphibole schists, quartzites and marbles. The sedimentary origin of the amphibole schists is evident from the following: 1. the geochemical characters of these rocks (El Manawi, 1991) including low Cr content (50 ppm in average); low TiO_2 content (0.3-1.0%); high silica content (up to 76%) and the scarcity of other trace

elements such as Ba, Ni, La, Ce, Nd, Sc, Co and Vl. 2. the bedded nature of these rocks and their characteristic mm to cm rhythmic intercalations of amphibole minerals, micas, quartz and calcite; and 3. the absence of relics of igneous textures or exsolution patterns. The lithofacies association of the metasediments and BIF and their syn-sedimentary structures (rhythmic bedding and lamination, cross lamination and flaser structure) suggest deposition in shelf environment. Iron was released from the hinterlands and transported into the basin of deposition. Syn-sedimentary fabrics and mineral assemblages of the Umm Nar BIF suggest primary precipitation as rhythmic alternations of ferruginous and calcareous shales or mudstones and silica gel that were later recrystallized during diagenesis and burial metamorphism into iron minerals, quartz, calcite and silicates (El Aref et al., 1993). They added that the crystallization of hematite, magnetite and stilpnomelane and the associated quartz, calcite, epidote and garnet were largely controlled by diagenesis and burial metamorphism and were formed during and after the development of the initial bedding parallel foliation ($S_1//S_o$). The intertongue relationship between the pebbly schists and BIF reflects lateral variations in the paleoenvironmental conditions of the upper zone of the metasediment succession. The pebbly varieties may indicate deposition in a shallow zone close to the continent, whereas the iron-rich muddy sediments may indicate deposition in a deeper zone away from the continent. During the Pan-African tectonic event and prior to the intrusion of grey granites, the metamorphosed sediments and BIF were tectonically overlain by the mlange rocks and these two units were in turn thrust over the "Shaitian" granite.

5. The rock assemblages, degree of metamorphism and tectonic setting of the BIF host metasediments can be correlated with the shelf deposits of the Early Proterozoic (?) pre Pan-African continental crust of the Egyptian Eastern Desert. The pre Pan-African rock assemblages of the Eastern Desert extends underneath the Late Proterozoic ophiolitic mlange rocks and the associated island arc assemblages and crop out in the cores of large swells or gneiss domes, e.g. Meatiq and Hafafit swells (El Gaby et al., 1988; Greiling et al., 1988); they include medium to highly metamorpbosed continental shelf facies, migmatites and granites that were deformed and diaphthoried during the Pan-African orogeny.

6. It was generally assumed that all the BIFs of the Egyptian Eastern Desert are intimately associated with Pan-African volcanogenic clastic sediments, wacke-rich sections or island arc association and they are thus of volcanogenic origin. This cannot be accepted for the studied Umm Nar BIF, since the present work showed that the iron bands of this area are closely associated with pre Pan-African shallow mature to semimature shelf sediments. Also, the conclusion of Sabet et al. (1976) and El Gaby et al. (1988) considering the Umm Nar BIF as a transitional facies between the BIFs of the northern part of the CED and the base metal sulphides in the southern part of CED, is not accepted since it can be only

applied to the ores associated with the Pan-African island arc assemblages.

7. According to the present conclusions, the Egyptian Precambrian BIFs can be preliminary reclassified into two main genetic types of different ages: 1. Early (?) Proterozoic BIF of pre Pan-African shelf environment, represented by the studied Umm Nar occurrence and 2. Late Proterozoic BIF of Pan-African island arc environment, represented by some other occurrences, e.g. G. El Hadid, W. Karim and El Dabah.

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الوضع الجيولوجى والتاريخ التكتونى لخامات الحديد الطباقى والصخور المصاحبة لها بمنطقة ام نار بالصحراء الشرقية ، مصر

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يهدف هذا البحث الى التعرف على الوضع الاستراتجرافى والتاريخ التكتونى لخامات الحديد الطباقى المتواجده فى منطقة ام نار بالصحراء الشرقية ، مصر.

وقد امكن تقسيم الصخور الاساسية بهذه المنطقة الى ثلاث وحدات صخرية رئيسيه وهى (١) الجرانيت التهشمى (شبه الجرانيت الشعيطى)، (٢) الصخور الرسوبية المتحولة وخامات الحديد المصاحبة لها و (٣) الميلانج الاوفيوليتى. يلى هذه الوحدات متداخلات من الجرانيت الرمادى ، الجابرو الحديث - والجرانيت الوردى.

اثبتت الدراسة ان صخور الجرانيت التهشمى تمثل الركيزة القديمة لصخور المنطقة والتى تتبع صخور ما قبل حركة البان افريكا. اما خام الحديد الطباقى فيمثل الوحدة الاستراتجرافية العلوية للصخور الرسوبية المتحولة والتى اثبتت الدراسة الحقلية والميكروسكوبية انها تمثل مع خامات الحديد رواسب رصيف قارى قديم تعرضت لتحول اقليمى قبل حركة صخور الميلانج الاوفيوليتى فوقها اثناء الحركة التكتونية للبان افريكا.

وعلى هذا فقد تم استنتاج ان الحديد الطباقى لمنطقة ام نار يختلف من ناحية بيئته الترسيبية ووضعه الجيولوجى عن العديد من خامات الحديد الطباقية الاخرى والمنتشرة فى الصحراء الشرقية والتى ترتبط استراتجرافيا مع صخور الجزر البركانية والميلانج التابعة لحركة البان افريكا.